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CO_2

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A Mid-Lower Troposphere Climatology of CO_2

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Overview

- 4-years of AIRS CO_2
- Motivation
  - RTA validation
  - AIRS climate monitoring
  - CO_2 transport; help understand sinks?
- Kernel function centered around 550 mbar
- Ocean/Night only clear FOVs; Good for validation, bad for sources/sinks and/or transport
- ECMWF used for temperature
- SST and TCW from AIRS (UMBC values)
- Validated via NOAA CMDL MBL, JAL, 2 ocean aircraft sites
- GOAL: provide useful data for modelers
- OCO will need AIRS mid-tropospheric CO_2

Mid-tropospheric CO_2 *is* Important!

Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO_2

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Measurements of midday vertical atmospheric CO_2 distributions reveal annual-mean vertical CO_2 gradients that are inconsistent with atmospheric models that estimate a large transfer of terrestrial carbon from tropical to northern latitudes. The three models that most closely reproduce the observed annual-mean vertical CO_2 gradients estimate weaker northern uptake of –1.5 petagrams of carbon per year (Pg C year^{-1}) and weaker tropical emission of +0.1 Pg C year^{-1} compared with previous consensus estimates of –2.4 and +1.8 Pg C year^{-1}, respectively. This suggests that northern terrestrial uptake of industrial CO_2 emissions plays a smaller role than previously thought and that, after subtracting land-use emissions, tropical ecosystems may currently be strong sinks for CO_2.

Our ability to diagnose the fate of anthropogenic carbon emissions depends critically on interpreting spatial and temporal gradients of atmospheric CO_2 concentrations (*1*). Studies using global atmospheric transport models to infer surface fluxes from boundary-layer CO_2 concentration observations have generally estimated the northern mid-latitudes to be a sink of approximately 2 to 3.5 Pg C year^{-1} (*2*–*5*). Analyses of surface ocean partial pressure of CO_2 (*2*), atmospheric carbon isotope (*6*), and atmospheric oxygen (*7*) measurements have further indicated that most of this northern sink must reside on land. Tropical fluxes are not well constrained by the atmospheric observing network, but global mass-balance requirements have led to estimates of strong (1 to 2 Pg C year^{-1}) tropical carbon sources (*4*, *5*). Attribution of the Northern Hemisphere terrestrial carbon sink (*8*–*13*) and reconciliation of estimates of land-use carbon emissions and intact forest carbon uptake in the tropics (*14*–*19*) have motivated considerable research, but these fluxes remain quantitatively uncertain. The full range of results in a recent inverse model comparison study (*5*), and in independent studies (*3*, *20*, *21*), spans budgets with northern terrestrial uptake of 0.5 to 4 Pg C year^{-1}, and tropical terrestrial emissions of –1 to +4 Pg C year^{-1}. Here, we analyzed observations of the vertical distribution of CO_2 in the atmosphere that provide new constraints on the latitudinal distribution of carbon fluxes.

Previous inverse studies have used boundary-layer data almost exclusively. Flask samples from profiling aircraft have been collected and measured at a number of locations for up to several decades (*22*–*24*), but efforts to compile these observations from multiple institutions and to compare them with predictions of global models have been limited. Figure 1 shows average vertical profiles of atmospheric CO_2 derived from flask samples collected from aircraft during midday at 12 global locations (fig. S1), with records extending over periods from 4 to 27 years (table S1 and fig. S2) (*25*). These seasonal and annual-mean profiles reflect the combined influences of surface fluxes and atmospheric mixing. During the summer in the Northern Hemisphere, midday atmospheric CO_2 concentrations are generally lower near the surface than in the free troposphere, reflecting the greater impact of terrestrial photosynthesis over industrial emissions at this time. Sampling locations over or immediately downwind of continents show larger gradients than those over or downwind of ocean basins in response to stronger land-based fluxes, and higher-latitude locations show greater CO_2 drawdown at high altitude. Conversely, during the winter, respiration and fossil-fuel sources lead to elevated low-altitude atmospheric CO_2 concentrations at northern locations. The gradients are comparable in magnitude in both seasons, but the positive

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†Deceased.

Data Used is Similar to Ours: (Once land is added)

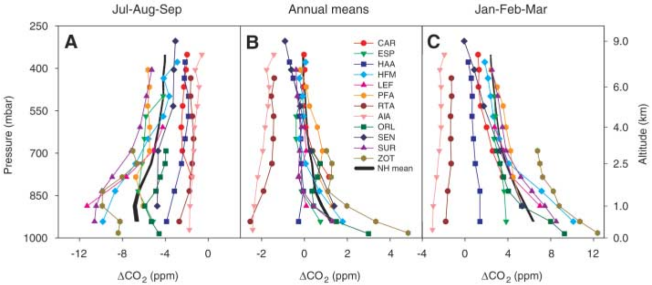


Fig. 1. Midday vertical CO_2 profiles measured at 12 global locations based on fits to samples binned by altitude and averaged over different seasonal intervals. Northern Hemisphere sites include Briggsdale, Colorado, United States (CAR); Estevan Point, British Columbia, Canada (ESP); Molokai Island, Hawaii, United States (HAA); Harvard Forest, Massachusetts, United States (HFM); Park Falls, Wisconsin, United States (LEF); Poker Flat, Alaska, United States (PFA); Orleans, France (ORL); Sendai/Fukuoka, Japan (SEN); Surgut, Russia (SUR); and Zotino, Russia (ZOT). Southern Hemisphere sites include Rarotonga, Cook Islands (RTA) and Bass Strait/Cape Grim, Australia (AIA). Profiles are averaged over Northern Hemisphere summer (**A**), all months (**B**), and Northern Hemisphere winter (**C**). A smoothed deseasonalized record from Mauna Loa has been subtracted from the observations at each site. Black lines in each panel represent Northern Hemisphere average profiles (center) and uncertainties (width) for the same times (*25*). The horizontal axis in (B) is zoomed by a factor of 2 relative to those in (A) and (C).

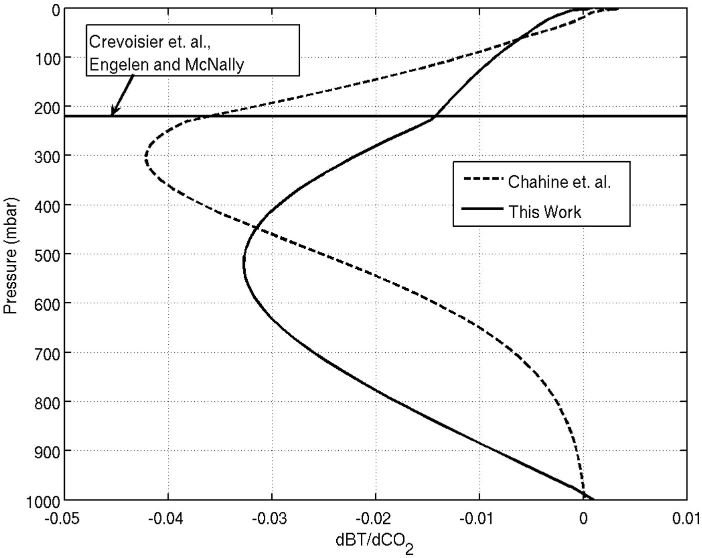
Methodology

- Use ECMWF $T(z)$, mean tied to radiosondes. Fit for SST and TCW using 2616 and 2609 cm^{-1} channels (night only).
- Solve

$$BT_i^{obs} - BT_i^{calc}(ECMWF) = \frac{dB_i}{dCO_2}\delta CO_2 + \frac{dB_i}{dT}\delta T_s$$

  for δCO_2 using 2+ channels.
- LW: Two channels, 791.7 cm^{-1} used for CO_2 and T_s; 790.3 cm^{-1} used for T_s only. Temperature insensitive.
- SW: 2392-2420 cm^{-1}; Temperature sensitive, 26 channels, diagnose ECMWF errors ($\sim$ 1 ppm jump on Feb. 2006)
- CO_2 zonally averaged into 4 degree latitude bins
- *Main difference between this work, and previous work: Lower peaking kernel functions.*

This Work: 791 cm^{-1} Channel $dR/d(CO_2^i)$ Peaks Closer to Surface



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Finding "Clean" CO_2 Channels

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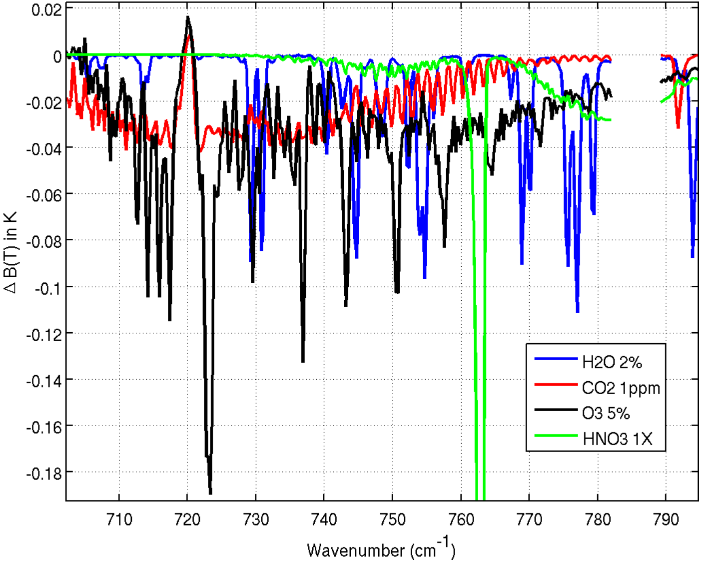
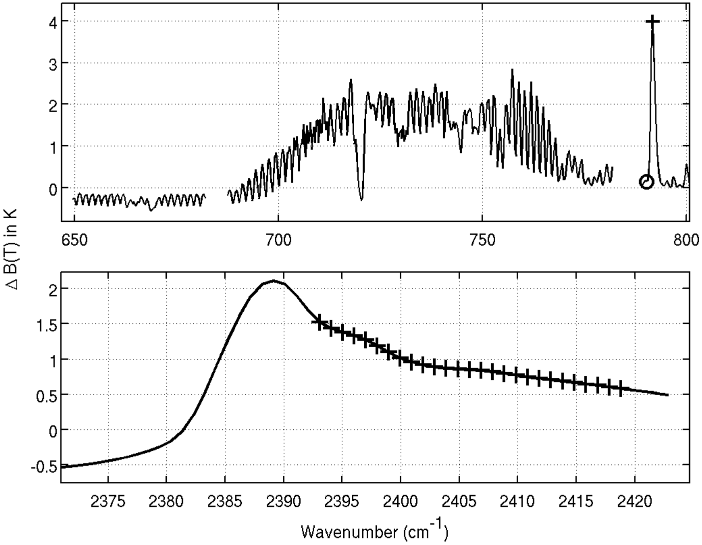


Ratio of dBT/d_{CO_2} to $dBT/dT_{profile}$

Why 791.7 cm^{-1} Channel



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Raw Biases, Northern Hemisphere Average

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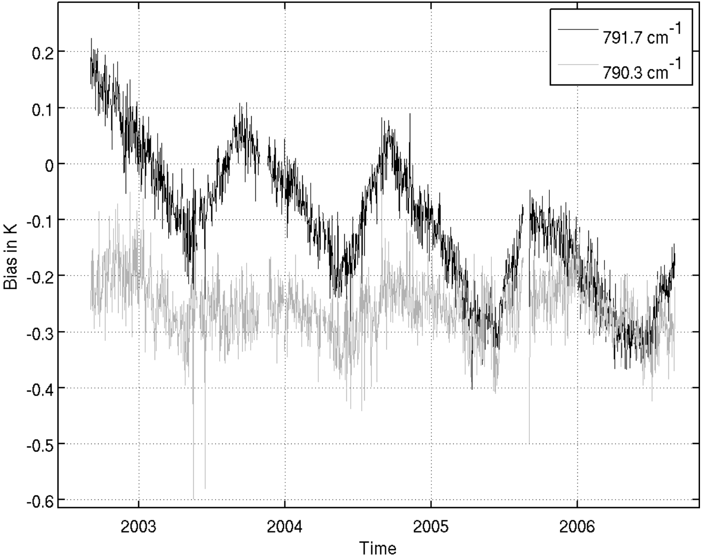

AIRS Calibrated (1-number, 1-time) Using MLO

MLO at ~650 mbar, close to peak of CO_2 W.F.

AIRS RTA only good to ~8 ppm for *any* channel (2%)

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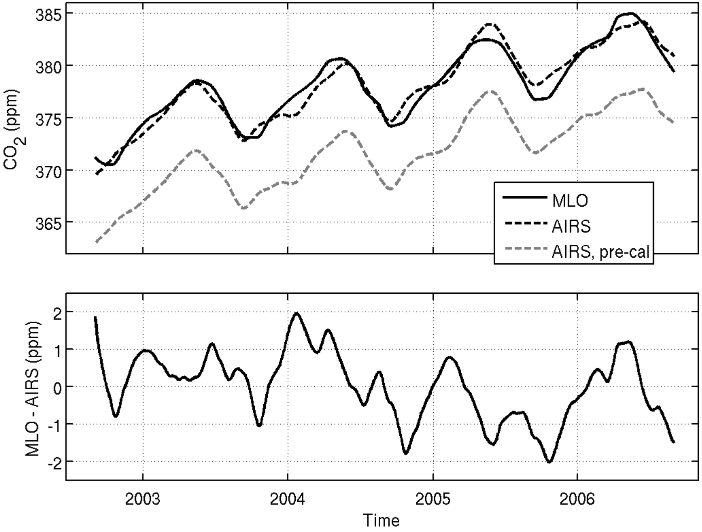

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AIRS 4-Year CO_2 Climatology

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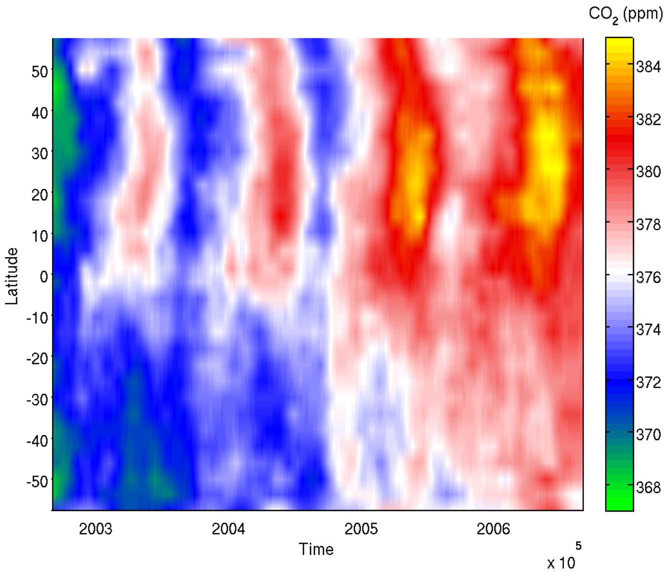
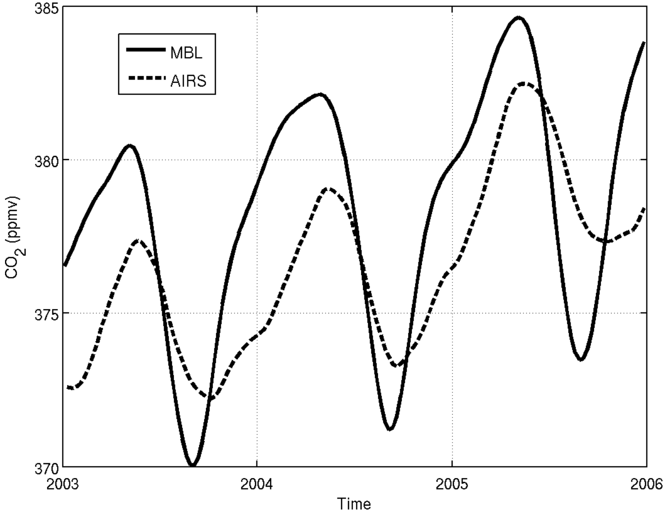


AIRS vs MBL; 25-50 Deg. Latitude



JAL Comparisons: 30N - 15N Latitudes

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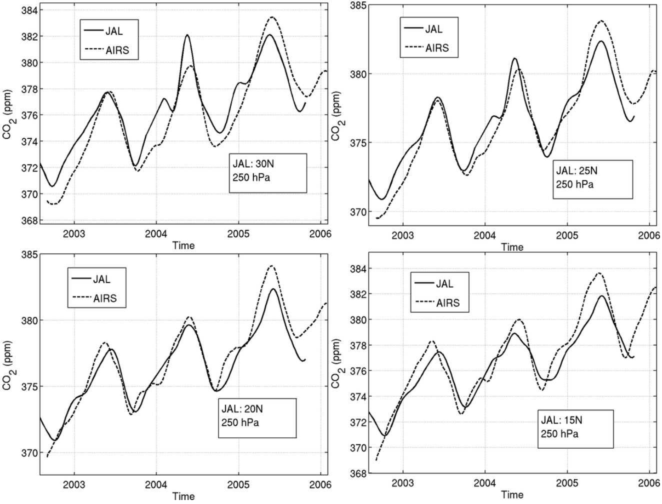

JAL Comparisons: 10N - 5S Latitudes

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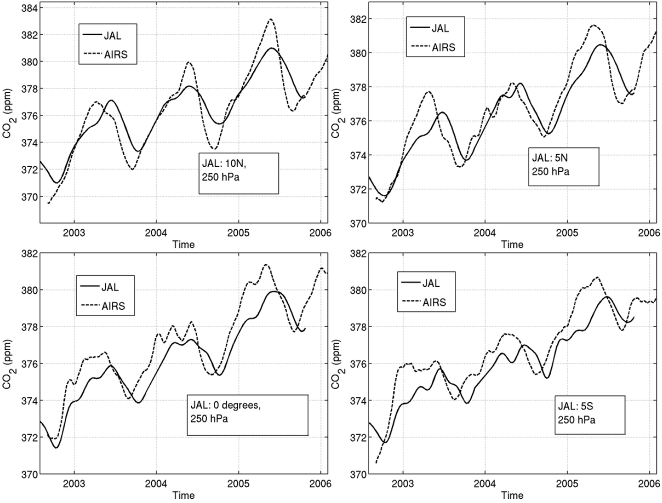
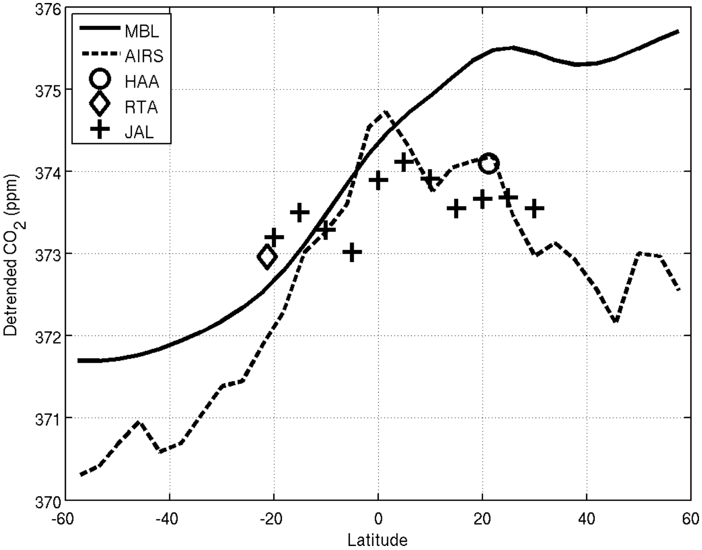


Validation of AIRS with MBL, JAL etc.



Validation of AIRS with Models

TRANSCOM Biosphere Models

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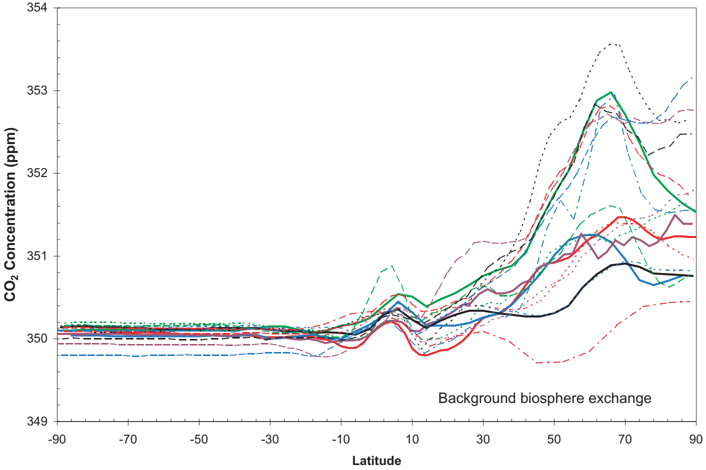

AIRS CO_2 vs NOAA/CMDL MBL

Top: MBL, Middle: AIRS, Bottom: AIRS-MBL

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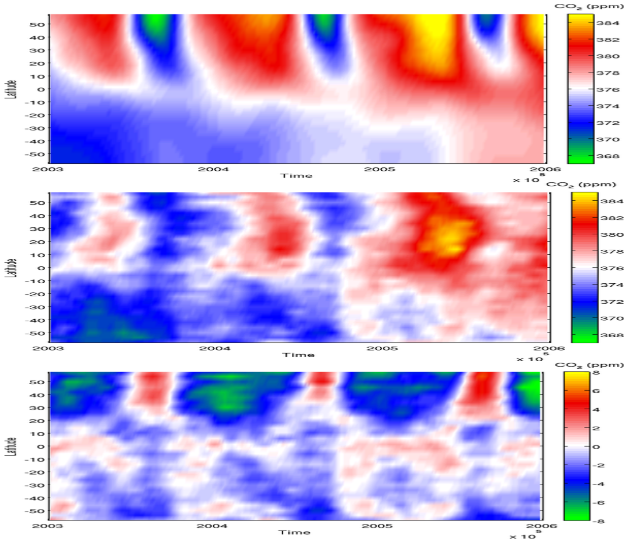

Example Model Simulations
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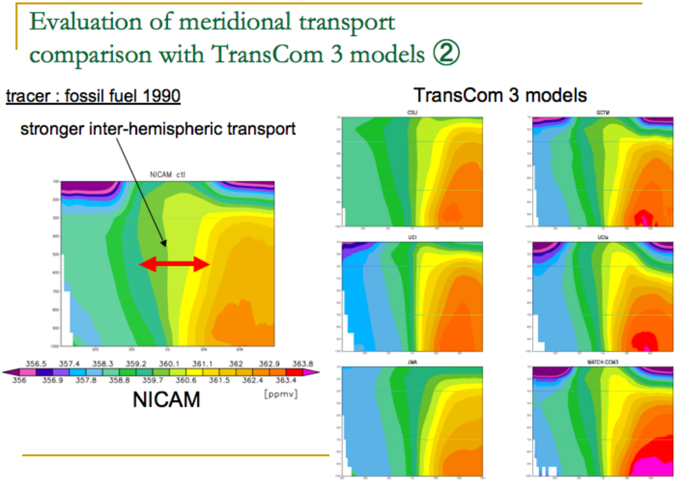

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AIRS Seasonal Amplitude vs MBL/JAL/etc.

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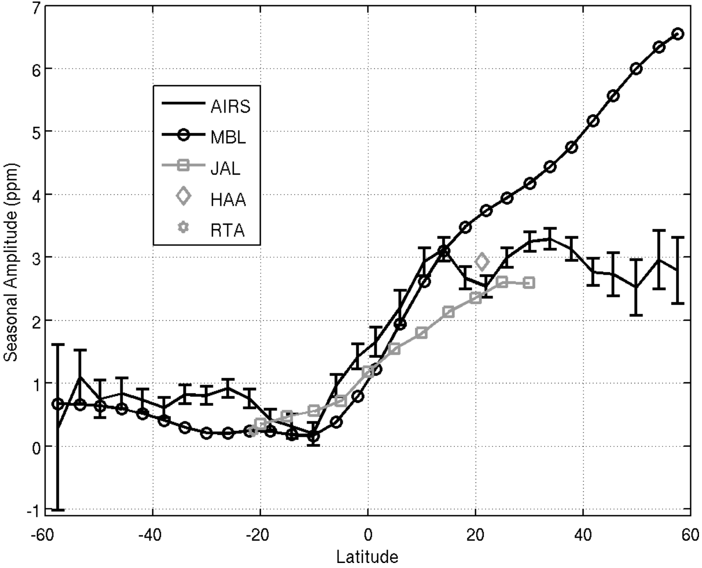

AIRS vs MBL Min/Max Amplitudes

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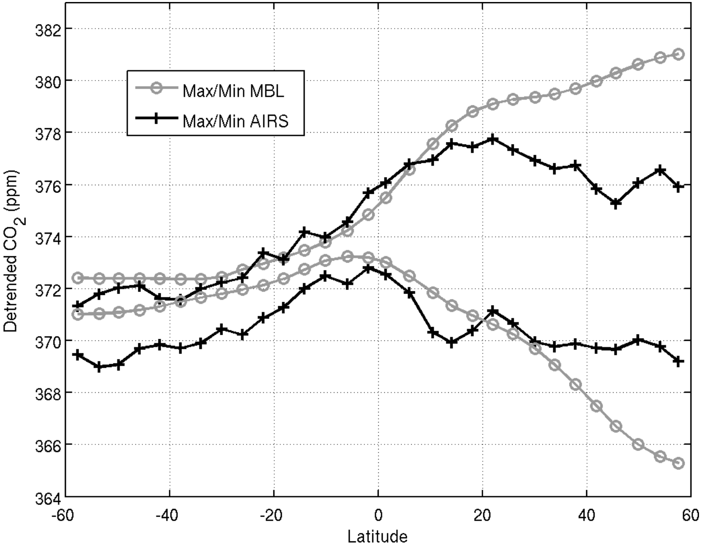
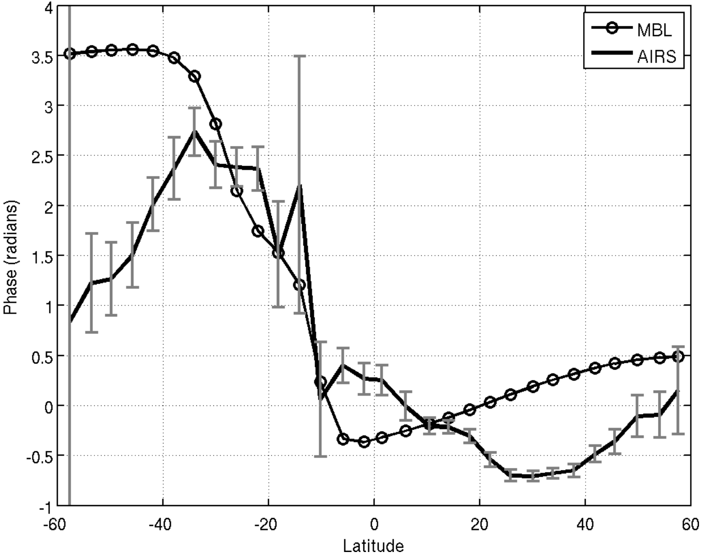


AIRS Seasonal Phase vs MBL



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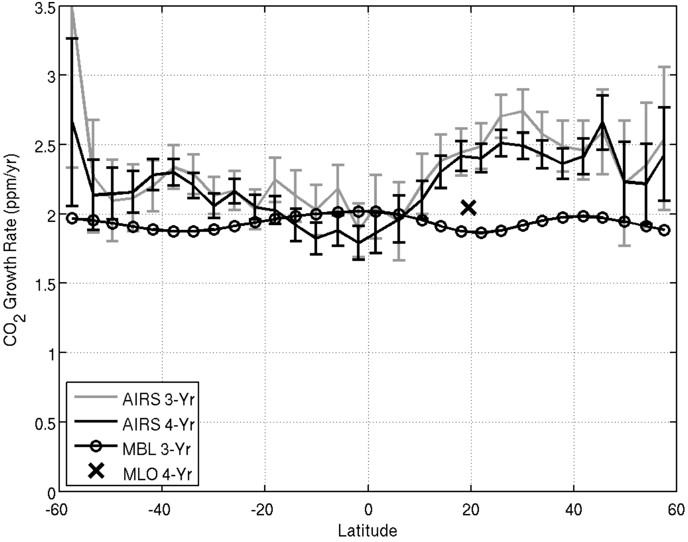
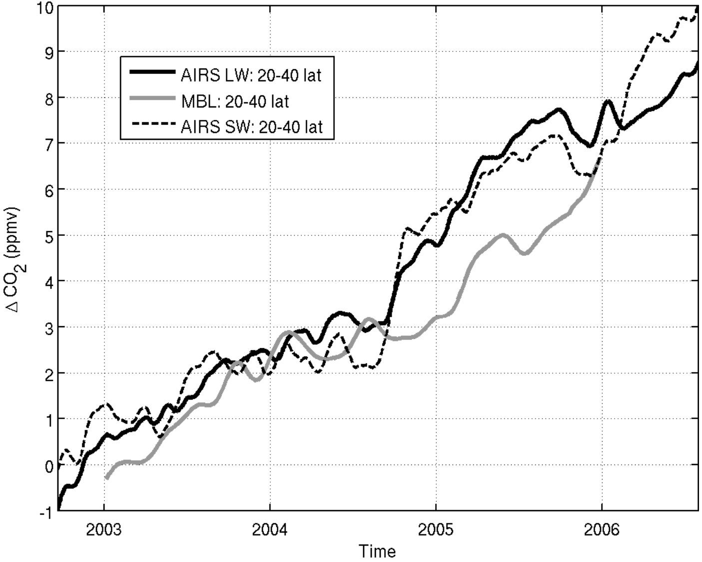
AIRS vs MBL/MLO CO_2 Growth Rates



AIRS vs MBL Growth Rates: Offsets and Harmonic Terms Removed



Rate Variability 20-40 Deg.lat; AIRS=2.44, MBL=1.92 ppm/yr
Blue Bars: AIRS=1.86, MBL=2.07 ppm/yr;
Red Bars: AIRS=2.56, MBL=2.88 ppm/yr

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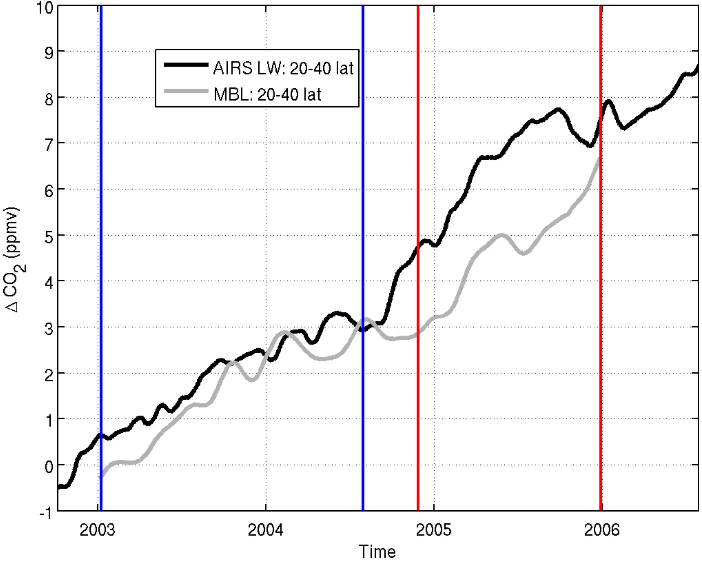

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1st Look: IASI vs AIRS CO_2

(Note: Using constant dBT/dCO_2)

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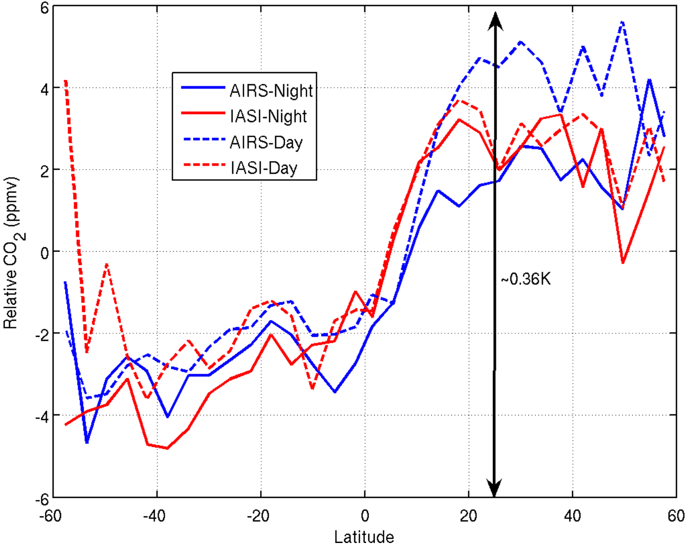

CO_2 Conclusions

- Excellent results using very clear FOVs over ocean
- Initial work shows similar results with cloud-cleared data, allowing more convective situations to be examined for transport
- Basic technique should work over land, first clear, then cloud-cleared data.
- This work sets a baseline on capability of AIRS, esp. with regard to trends.